NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

TECHNICAL MEMORANDUM

No. 1104

THE INFLUENCE OF THE JET OF A PROPULSION UNIT

ON NEARBY WINGS

By H. Falk

Reprint

Der Einfluss eines Triebwerkstrahles auf einen
in Nahe befindlichen Flugel

Untersuchungen und Mitteilungen Nr. 3200

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ABSTRACT: The present investigation was intended to
            ascertain how far a tail unit is subject to
            disturbances by the jet of a propulsion unit.
            The parameters upon which this disturbing
            influence depends, and the values it reaches,
            had to be determined.

I. STATEMENT OF THE PROBLEM

Additional forces are probably exerted upon a
supporting wing, for instance a tail unit, if it is
located behind a propulsion unit with an emitted jet.
These forces must be traced back to the presence of the
jet. Figure 1 represents schematically such an arrange-
ment. Forces of this kind may disturb the stability of
flight. A basic test will help us to ascertain the
influential parameters and to determine the magnitude of
the forces.

[*]"Der Einfluss eines Triebwerkstrahles auf einen in
Nähe befindlichen Flügel," Deutsche Luftfahrtforschung,
Untersuchungen und Mitteilungen Nr. 3200.

Essentially, there are two effects of decisive
importance. The first effect is based on potential
theory and was already treated by P. Ruden (1) for the
case of a plane wing in the proximity of a plane jet
(or of a region with slow flow). The pressure distri-
bution on the wing is disturbed by the uneven distribution
of the total pressure; additional forces result. There-
fore, the thickness of the wing will be of foremost
importance in this effect. (Other quantities of influence
will be discussed later.) An infiritely thin wing at
zero angle of attack will not experience any forces.

The second effect is founded on the intermixing of
the jet with the surrounding flow not based on potential
theory. The turbulent spreading causes the appearance
of a velocity component directed toward the jet in certain
regions. These conditions were discussed in numerous
reports since W. Tollmien (2); recently they were also
treated numerically for the core of the rotationally
symmetrical jet by O. Pabst (3) and H. Szablewski (4).

The following parameters are probably the most
influential ones: the propulsion jet, which for this
investigation is assumed to be unheated, will be charac-
terized by its velocity v_A in the exit of the pro-
pulsion unit. v_A differs from the undisturbed oncoming
flow v_0. Apart from the ratio v_A/v_0 of the two
velocities the difference $v_A - v_0$ will also play an
important part. (Compare (5).)

The position of the wing in relation to the jet will
be most important for the interference effect upon the
wing; therefore, in our case of the rotationally symmetrical
jet the coordinates x and z of for instance the
loading edge in the coordinate system characterized in
figure 1 will be of main importance. The wing span and
the coordinate of the wing in the direction of the span
are not considered in our investigation since we assume
the span in both directions to be large compared with the
jet diameter. On the wing itself its thickness d and
its chord l will be of influence, the ratio d/l
no less than the ratio d/d_A (thickness of the wing-
jet diameter). The profile form, which will also be of
influence, was changed but slightly in our experiments
since existing wings are to be used for the measurements;
we limited ourselves to symmetrical profiles. Both the

propulsion unit and the wing may be inclined toward. the
direction of the oncoming flow and so form an angle with
respect to each other also. Investigations were made
only for conditions of symmetry so as to hold down the
extent of the measurements; moreover, the wing was always
adjusted in the direction of the undisturbed oncoming
flow so that without interference effect the lift was
zero. In most of the experiments the jet left the pro-
pulsion unit in the direction of the oncoming flow. Only
in a few cases the axis of the propulsion unit was
inclined at an angle α toward the oncoming flow.

II. TEST PROCEDURE

Figure 2 gives a schematic representation of the
experimental arrangement. A model propulsion unit with
a built-in blower which had been used before by
H. Baeuerle (6) was suspended in the open jet of
wind tunnel III (1.0 × 1.5m). A wing was supported in
the customary manner by the three-component balance behind
the propulsion unit in the center of the jet; however,
only the lift was measured. The relative position of
propulsion unit and wing was changed by fixing the wing
and shifting the propulsion unit upward and in the direction
of the opening of the nozzle. All distances were measured
in units of d_A (d_A diameter of the exit opening of the
propulsion unit $= 70mm$). In the x-direction the
distances $x/d_A = 1, 2, 4, 6, 8$ and in z-direction the
region $0 \leq z/d_A \leq 4$ were measured. Seven different
ratios v_A/v_0 , namely $v_A/v_0 = 0.77, 1.85, 2.05, 2.5, 3.0$,
and 4.0 are apportioned to each point behind the pro-
pulsion unit. The first value corresponds to the model
propulsion unit at rest. Additional measurements were
taken for static conditions. The measurement does not
exactly conform to the value $v_A/v_0 = \infty$ since the whole
wind-tunnel jet had been put into a slight motion.
Generally, the jet velocity v_A was kept constant at
90 m/s; v_0 was changed accordingly.

Three different wings with symmetrical profiles and
the following characteristics were at our disposal for
measurement:

	l (mm)	Λ	d/l	d/d_A	l/d_A
Wing I	300	2.0	0.16	0.69	4.3
Wing II	175	3.4	0.10	0.25	2.5
Wing III	125	4.0	0.09	0.16	1.5

Wing I had a modified Joukowski profile with increased angle of the trailing edge and straight sides; wings II and III had the customary NACA drop shape.

The angles of attack of the propulsion unit $a = 3^\circ$ and $a = 6^\circ$ on wing II were measured in the same arrangement. Since at $a = 0$ the flow is no longer symmetrical to the axis of the propulsion unit, negative z-values also had to be measured simultaneously. In order to keep out of the disturbance range of the suspension of the propulsion unit the latter was tilted in opposite direction at the same angle of attack; therefore, the wing always remains in the region underneath the propulsion unit.

III. RESULTS OF MEASUREMENTS

The results are represented graphically in the form of a lift coefficient c_a^* in dependency on z/d_A for various x/d_A and v_A/v_0 in figures 3, 4, and 5. The lift is referred to the stagnation pressure of the free stream $\rho v_0^2/2$ and to the area $d_A \times l$. The jet diameter d_A rather than the span was inserted as the length in order to keep the result independent of the span. Figure 3 includes all the values for the wing I with an angle of attack $a = 0^\circ$. The course of the curve shows a distinct maximum and consequently an asymptotic falling off toward zero with increasing z-values. The rise from zero toward the maximum values is steep compared with the decline. The curves for negative values are to be inverted with respect to the zero point; this process also inverts the sign.

The extreme value of c_a^* lies for all x-values near the jet boundary; with increasing x it moves slightly outwards. With v_A/v_o diminishing the maximum value c_a^* also decreases. The lateral force which is directed toward the jet for $v_A/v_o > 1$ should have the opposite direction for $v_A/v_o < 1$. This circumstance is not always brought out clearly by the measurement, due probably to inaccuracies in measuring.

Generally speaking, the same conditions prevail for wings II and III as for wing I as shown in figures 4 and 5. The course of the curve retains the same form; nor does the local position of the maximum change. The maxima for the three wings differ in size only.

Figure 6 shows the results of measurements for static conditions. Here the lift coefficients c_a^{**} are referred to $\rho v_A^2/2$. The graphs show the course for various x-values.

The measurements for the wing with the propulsion unit at an inclination are compiled in figures 7, 8, and 9. The curves are not symmetrical with regard to the zero point. A range of direct influence must be distinguished from a region of interference. If the jet is pointed at the wing there results in our arrangement a negative lift of the wing. In the main, the same course appears for the positive c_a^* values as indicated for $a = 0^o$. The negative c_a^* values attain maximum values which differ considerably from the positive ones. The slope toward zero is much greater for the negative values than it was in the positive section. With increasing x the point of transition through the zero line approaches higher z-values.

A number of corrections had to be introduced in evaluating the results of measurement; these corrections shall be treated subsequently. Each wing showed a small lift even without propulsion jet; this lift is caused by the one-sided suspension of the propulsion unit. Another effect of disturbance is to be traced back to the position of the propulsion unit with respect to the opening of the nozzle. A normal formation of the open jet is increasingly impeded the more the propulsion unit

is shifted from the center of the jet toward the
boundary. The greatest disturbance is to be expected
for the values $x/d_A = 8$ and relatively high values
of z/d_A because in this case the propulsion unit is
suspended quite near the opening of the nozzle and
causes the maximum deflection of the jet. Naturally,
the deformation of the jet also depends upon the force
of the propulsion jet and the inclination of the pro-
pulsion unit.

The simplest method to eliminate the disturbances
indicated above is to extend the measurement to z/d_A
values of such magnitude as to guarantee the nonappear-
ance of the described effect. Thus one determines the
asymptotes which can then be used as zero line. This
mode of procedure worked reliably in every case.

The method was rendered more difficult by measuring
the negative z values (as indicated above) in a way
different from the one used in measuring the positive
values; it was aimed at reducing the disturbance caused
by the suspension of the propulsion unit. It may be the
case that the curves do not join at $z = 0$. A mean
value was used in the evaluation.

IV. APPROXIMATE REPRESENTATION OF THE RESULTS

So far the results were discussed as they were
obtained for the special arrangements. Now we shall try
to find relations which will make it possible to draw
conclusions as to any arrangement. To this end the
specific conditions have to be eliminated from the results
of the experiments.

The definition of the c_a^* value given above contains
already certain generalizations. First of all the diameter
of the jet d_A was introduced as a reference quantity;
hereby the span of the wing was eliminated. The span was
for each case tacitly assumed to be so large as to com-
pletely cover the region of interference. As a second
step the wing chord l was removed by selecting $d_A \times l$
as reference area. The thickness of the wing d and
and the ratio v_A/v_o and difference $v_A - v_o$, respectively,
were recognized as the most important remaining parameters.

c_a* was assumed to be proportional to $v_A - v_o$ or
$v_A/v_o - 1$; this proportion is physically plausible for
the mixing effect only, not for the potential flow. The
remaining quantity

$$\frac{c_a^*}{\dfrac{v_A}{v_o} - 1} = \frac{A}{\dfrac{\rho}{2} v_o^2 d_A \times l\left(\dfrac{v_A}{v_o} - 1\right)}$$

will be a function of the thickness of the wing d and
first of all, based on considerations of potential theory,
a function of the ratio d/l. Here also we assumed a
linear dependency. Furthermore the ratio of d/d_A
(thickness of the wing/diameter of the jet) also will
appear; for it is easily conceivable that a thin jet will
have less influence than a jet of great extent as compared
to the thickness of the wing. We determined the kind of
this dependency empirically, using the maximum values
c_{am}*. It becomes obvious that d/d_A also will appear
in linear dependency, and that the maxima in all measure-
ments can be reproduced amazingly well by the relation

$$c_{am}^* = 1.10 \left(2 - \frac{d}{d_A}\right) \frac{d}{l} \left(\frac{v_A}{v_o} - 1\right)$$

as shown in figure 10. Therefore, the value of c_{am}*
increases with v_A/v_o increases with d/l and decreases
with d/d_A. We now tried to represent the whole course
of curves over z/d_A also by approximate curves, and, to
this end, divided the measured c_a* values by c_{am}*.
Figure 10 shows that here also it is possible to draw
a uniform curve through all the experimental points. The
dispersion is, in the main, unsystematic and the points
with the largest dispersion on the average may be
attributed to the two small values $v_A/v_o = 2.05$ and
$v_A/v_o = 1.85$; there the inaccuracies of measurement in
this graph are, quite naturally, most noticeable. (These

values are given with crossed out signs.) In this way we
obtain the approximate curves represented graphically in
figure 11.

These curves, together with the formula for c_{am}^{*}
may be used as a good approximation in the general case.
The region of validity will be given by about

$$x/d_A \leq 6$$

$$1 \leq \frac{v_A}{v_0} \leq 4$$

$$d/d_A \leq 1$$

however, the limits of the region were not yet accurately
defined. In limiting the region of x/d_A it must be
pointed out that the approximation was set up mainly for
the case where the potential core is not yet completely
reduced so that still the full amount $(v_A - v_0)$ appears
as velocity difference. For greater clarity the spreading
of the jet is represented graphically in figure 12.

The measurements for static conditions have to be
treated specially because of $v_0 = 0$. In this case we
divided the measured c_a^{*} values by the expression

$$f(d,d_A,l) = 1.18\left(2 - \frac{d}{d_A}\right)\frac{d}{l} ;$$

it became obvious that the measurements on the three wings
approximately coincide again. The resulting approximate
curves are indicated in figure 11. Deviations from the
course of the curve appear at $x/d_A = 8$ where the
potential core has already been reduced to zero (compare (5)).

This evaluation does not include the case of yawed
flow since the relations there are not yet sufficiently
clarified because of the unknown course of the jet. Further
investigations in this respect are intended.

V. SUMMARY

The mutual influence of a jet produced by a pro-
pulsion unit and a nearby wing was investigated. The
tests concerned mainly three different wings. These
wings were suspended in such a manner that they had
practically no lift without the influence of the jet;
the interference lift was measured. The most important
qualtities of influence can be determined from the
results. They are, apart from the geometrical position
of the wing toward the jet, the velocity ratio v_A/v_O
the chord l of the wing and the thickness of the
wing d; for d both the ratios d/l and d/d_A
(relation to the diameter of the jet) are of importance.
Approximate formulas for the lift to be expected were
given. A few short tests treat the case of a propulsion
unit in yawed flow. According to the results it is
possible to fix, for instance, the position of a tail
unit in such a way that the influence in the case of
straight flow is only very slight. Noticeable and
unwelcome effects are to be expected only when the jet
is pointed directly at the wing or is tangent to it.
Therefore, for a project, knowledge of the course of the
jet under as many different flight conditions as possible
should be emphasized. These questions are also especially
important with respect to the problem treated here,
because the spreading of the jet depends considerably
upon the form of the fillet for the installation and upon
the possibility of a sufficient ventilation from all
sides. This dependency is especially obvious where the
propulsion unit has been installed on the outside.

Translated by Mary L. Mahler
National Advisory Committee for Aeronautics

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Figure 1.

Fig. 1

Fig. 2

NOZZLE
1.0m x 1.50m

PIVOT

70

d_A

WING I

V

z

x

$\ell = 300$

EXIT CONE 1.75 m Ø
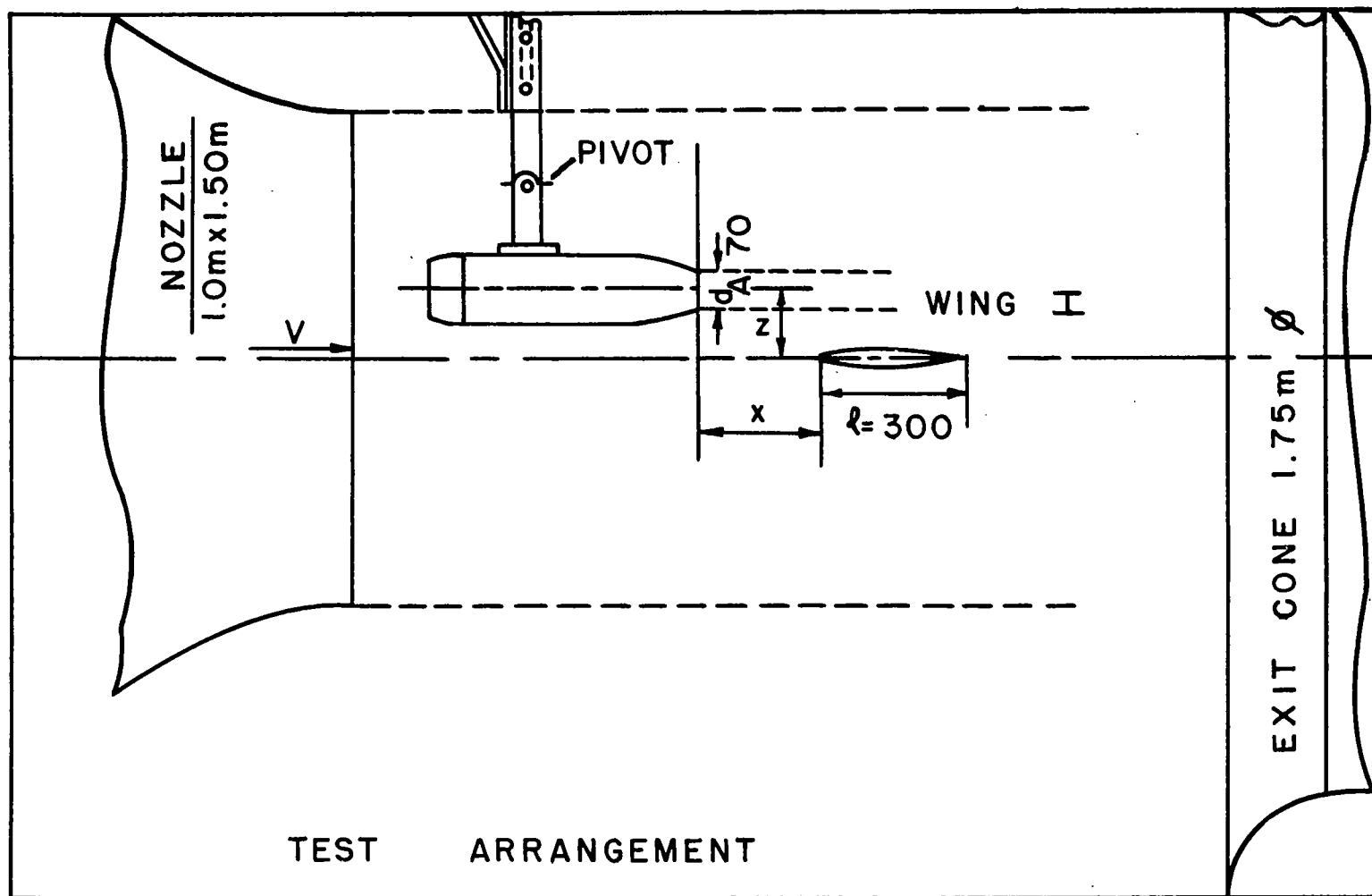
TEST ARRANGEMENT

Figure 2.
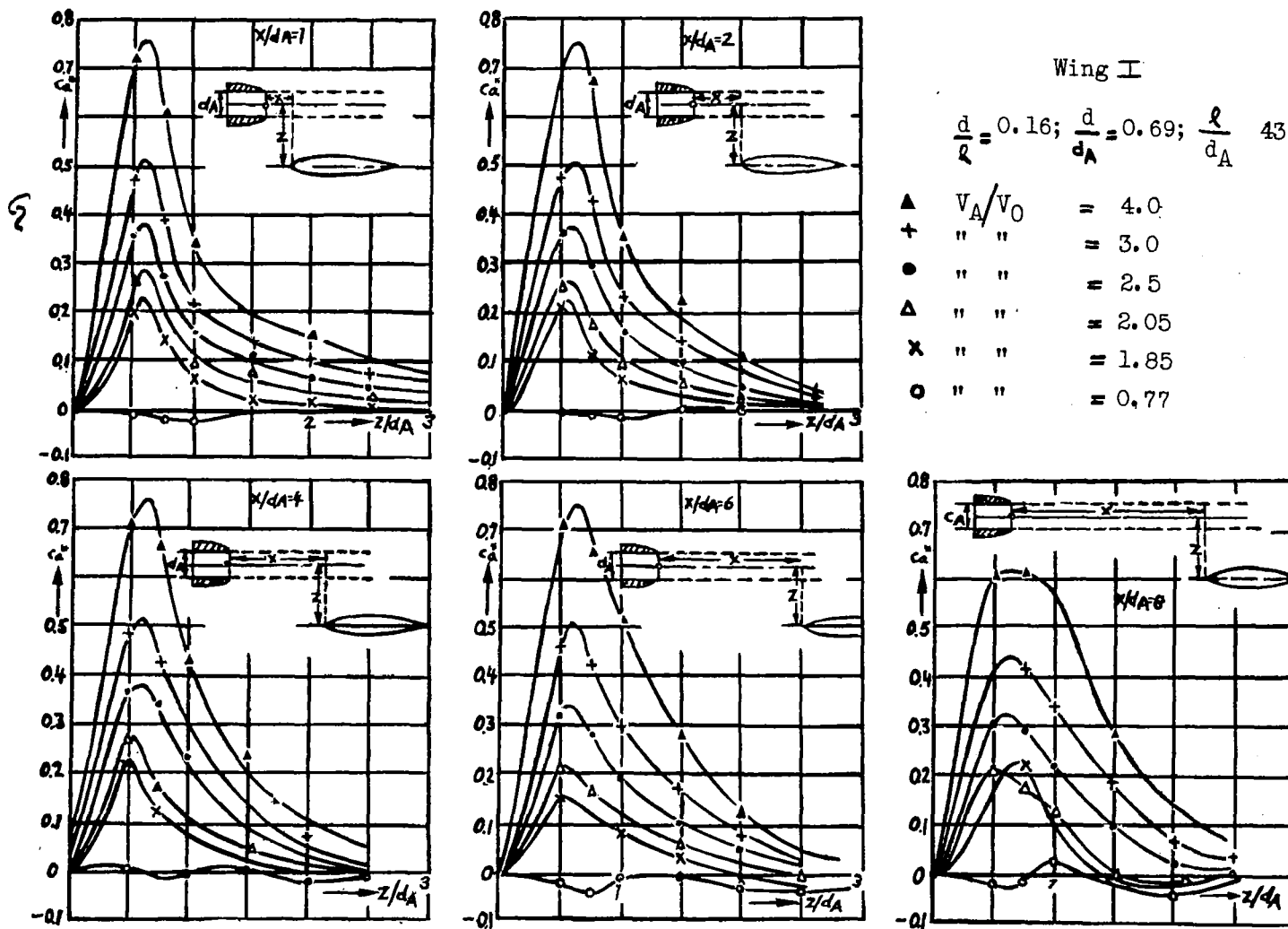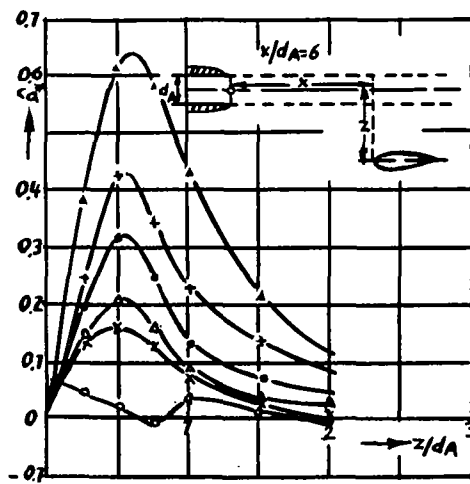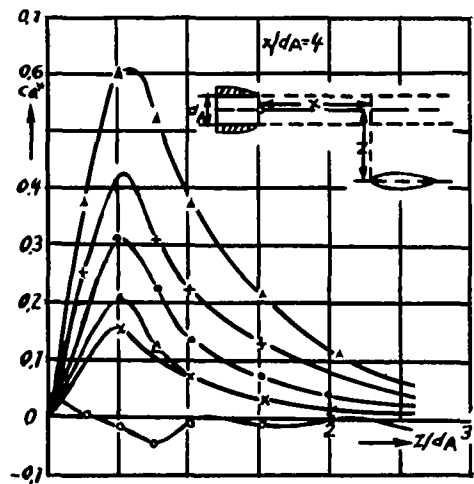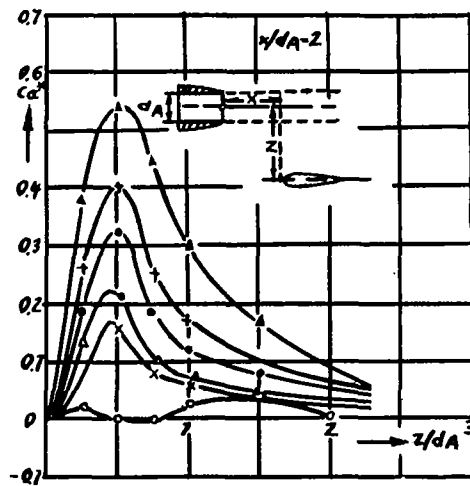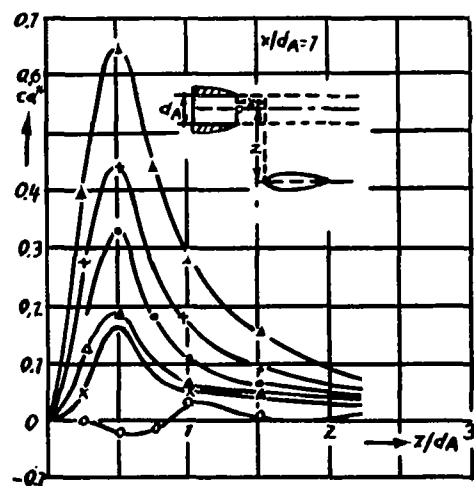
Figure 3.

Fig. 3

Fig. 4
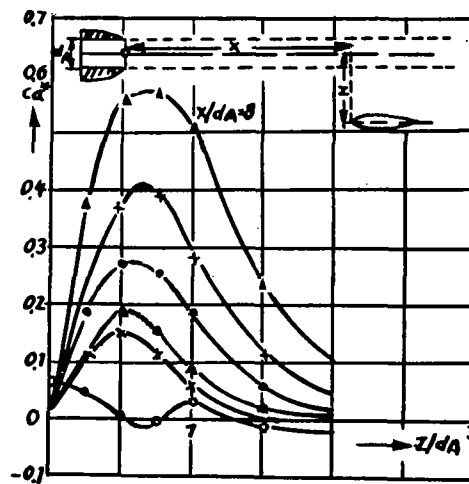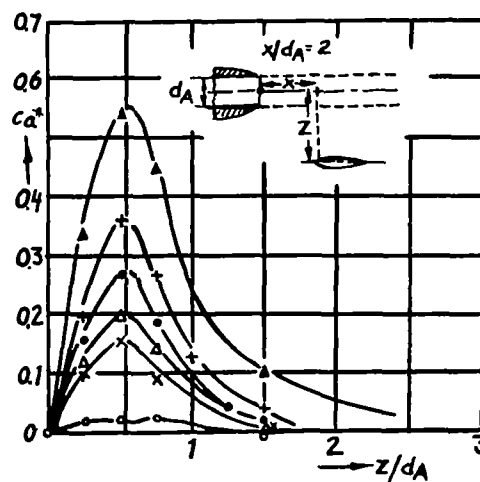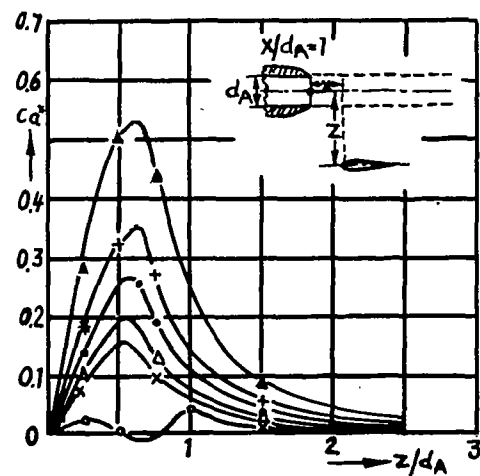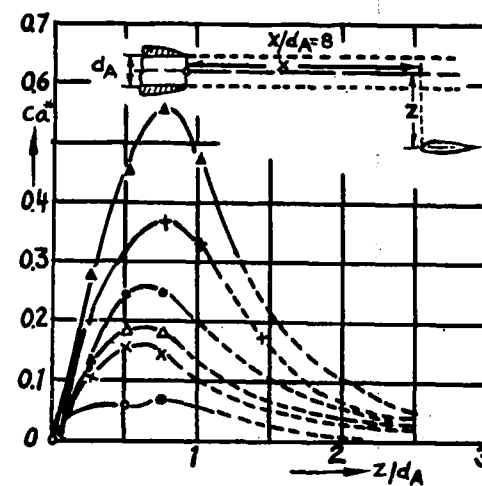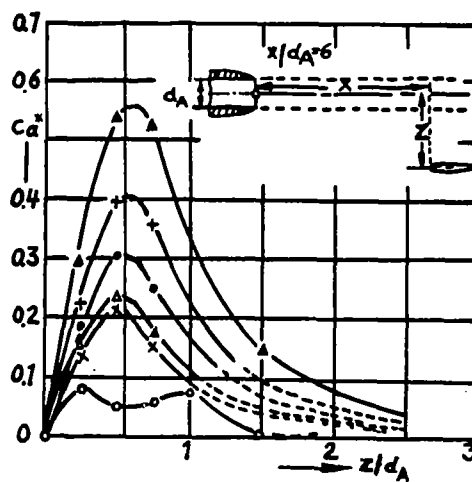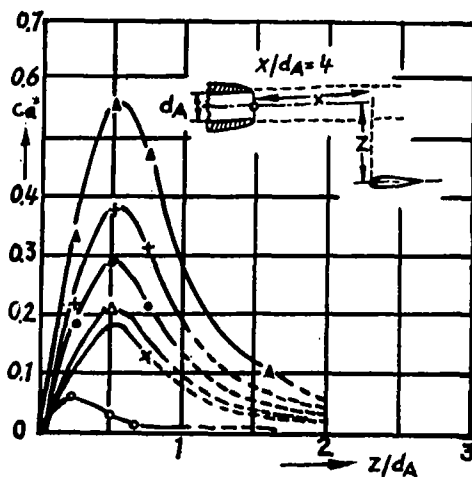
Figure 4.

Figure 5.

Fig. 5

Fig. 6   NACA TM No. 1104

Figure 6.

Wing II $\dfrac{d}{\ell}=0.70$; $\dfrac{d}{d_A}=0.25$; $\dfrac{\ell}{d_A}=2.5$ $\alpha=3°$

$x/d_A=2$

c_q*

$x/d_A=8$

c_q*

$\longrightarrow z/d_A$

$\longrightarrow z/d_A$

Figure 7.

Fig. 7

Fig. 8
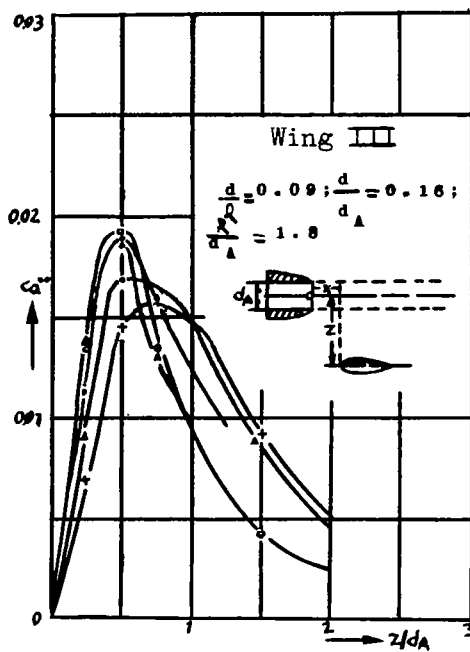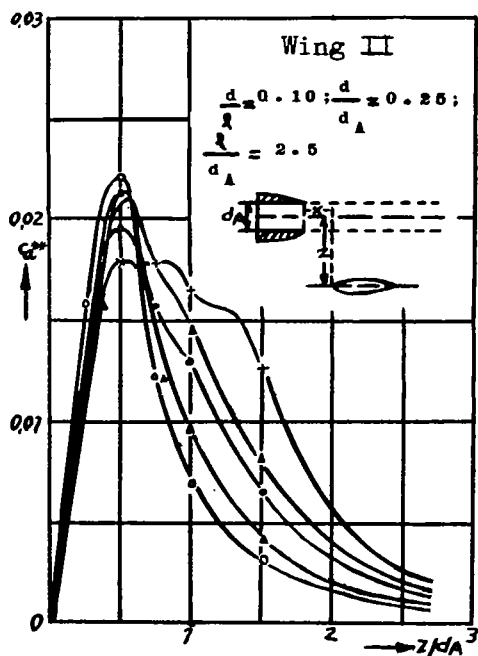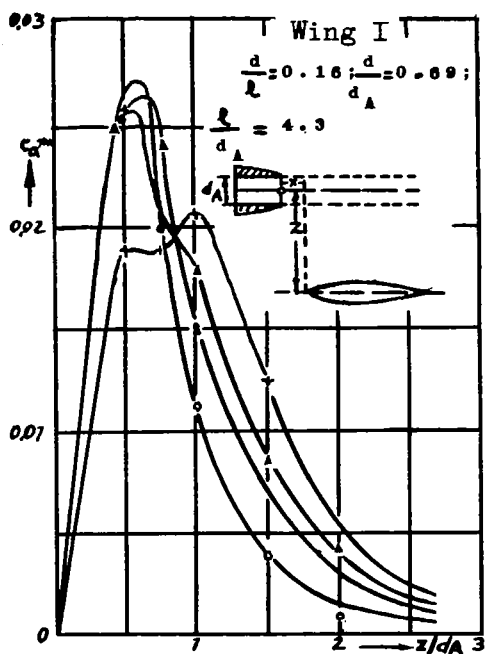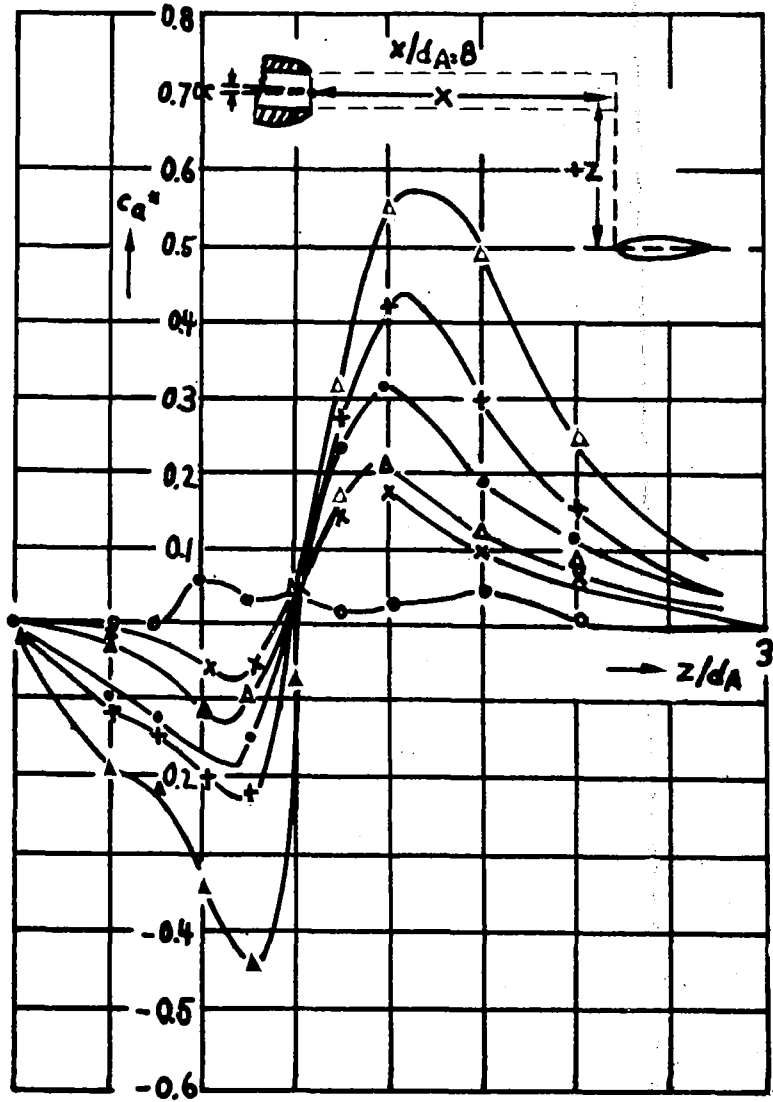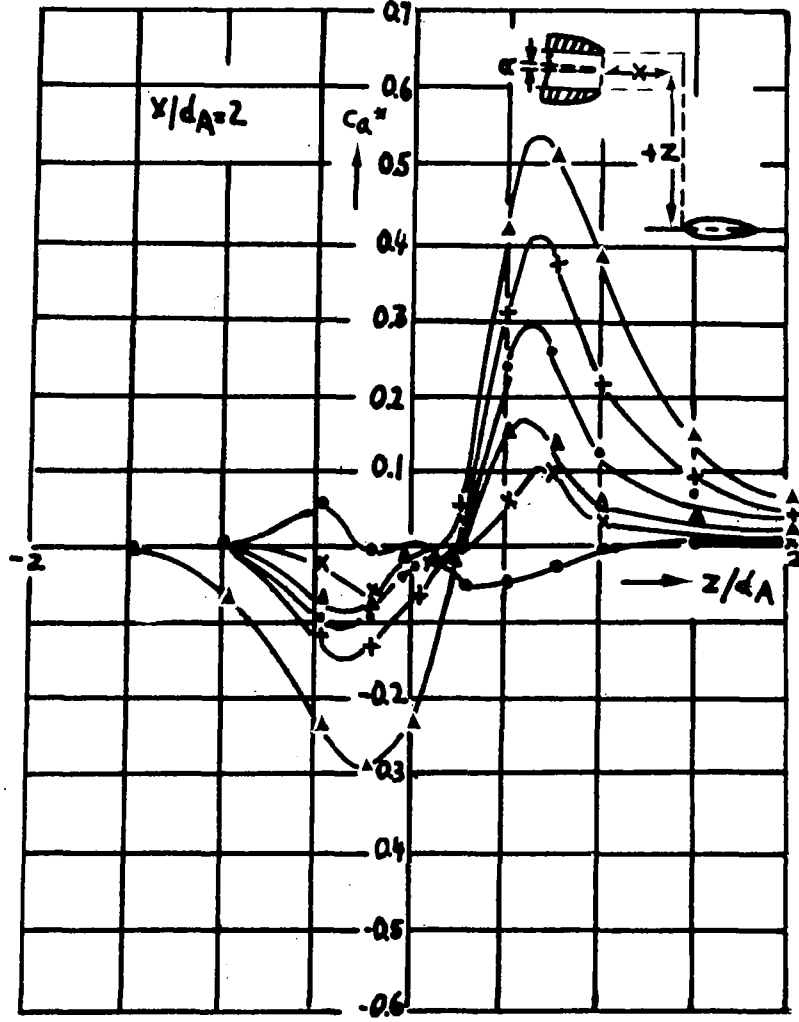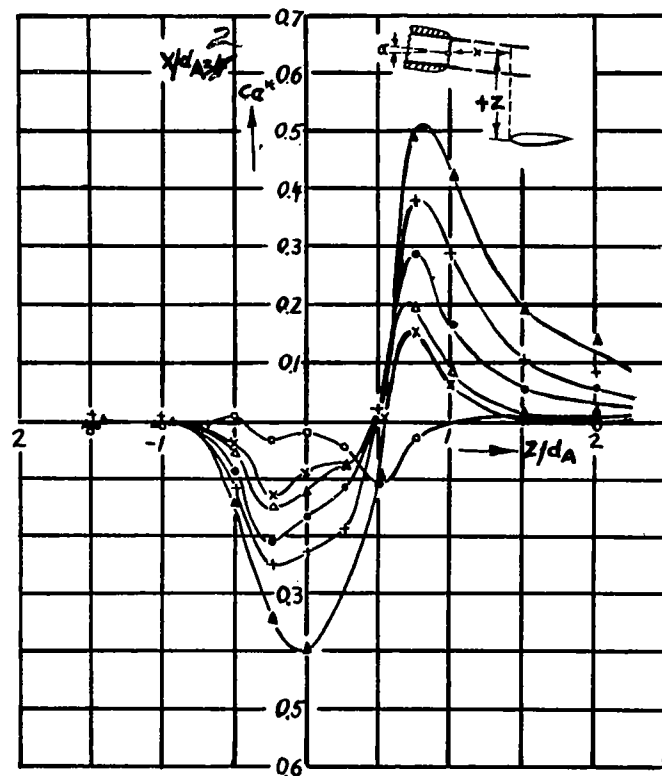
Wing II

$$\frac{d}{\ell} = 0.10; \quad \frac{d}{d_A} = 0.25; \frac{\ell}{d_A} = 2.5$$

$$\alpha = 6°$$
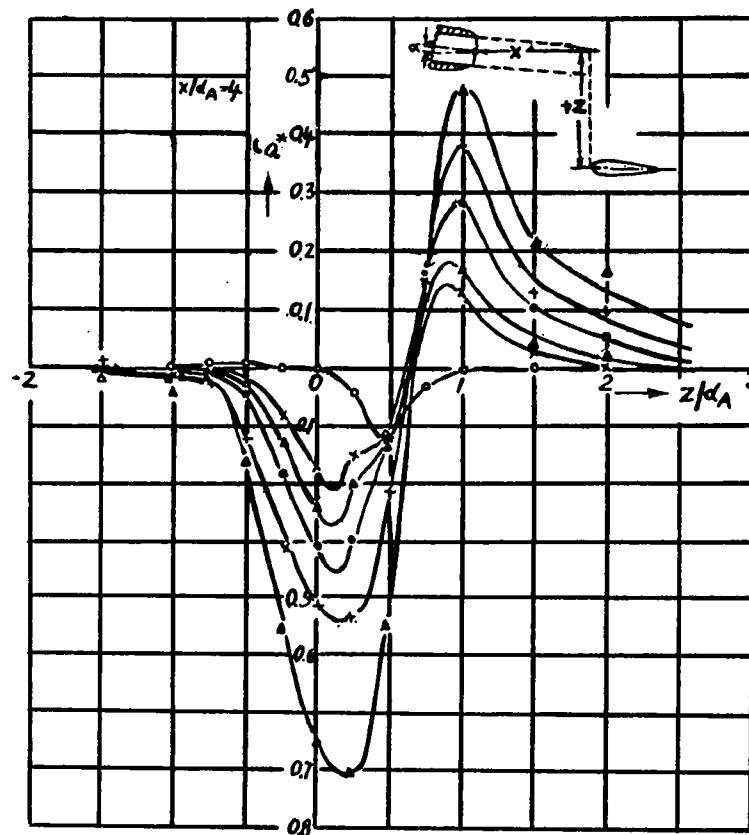
Figure 8.

Figure 9.

Fig. 9

Fig. 10

Figure 10.

Figure 11.

Fig. 12

Figure 12.